

## **CLAIMS**

1. A method for establishing a MPLS Traffic Engineering LSP between a head-end node and a tail-end node across multiple autonomous systems, said method  
5 comprising:

providing a plurality of path computation elements, each associated with a corresponding autonomous system;

using said plurality of path computation elements to recursively compute a virtual shortest path tree between a first autonomous system including said head-end node and a  
10 second autonomous system including said tail-end node; and

computing a path of said MPLS Traffic Engineering LSP using said shortest path tree.

2. The method of claim 1 wherein a root of said virtual shortest path tree  
15 comprises said tail-end node and other nodes of said shortest path tree are border routers connecting ones of said multiple autonomous systems.

3. The method of claim 1 wherein computing a path comprises employing CSPF.

4. A method for operating a first path computation element in a first autonomous system to participate in establishing an inter-autonomous system Traffic

5 Engineering LSP between a head-end node and a tail-end node, said method comprising:

receiving virtual shortest path tree information from a second path computation element in a second autonomous system, said virtual shortest path tree information identifying a shortest path tree rooted at said tail-end and extending to one or more border routers linking said first autonomous system and said second autonomous system;

10 performing computations based on said received virtual shortest path tree information to determine a revised virtual shortest path tree, said revised virtual shortest path tree extending from said tail-end node to one or more border routers linking said first autonomous system and a third autonomous system; and

sending information identifying said revised virtual shortest path tree to a third  
15 path computation element in said third autonomous system.

5. The method of claim 4 wherein said information identifying said revised virtual shortest path tree identifies paths through border routers of said revised virtual shortest path tree without identifying intermediate nodes between said border routers of  
20 said revised virtual shortest path tree.

6. The method of claim 5 wherein said information identifying said revised virtual shortest path tree identifies paths through border routers of said revised virtual shortest path tree and identifies intermediate nodes between said border routers of said revised virtual shortest path tree.

7. The method of claim 4 further comprising:

prior to receiving said virtual shortest path tree information from said second path computation element, receiving a path computation request from said third path computation element and forwarding said request to said second path computation element.

8. A method for operating a first path computation element in a first autonomous system to participate in establishing an MPLS Traffic Engineering LSP from a head-end node in said first autonomous system to a tail-end node in a second autonomous system, said method comprising:

receiving a path computation request from said head-end node;

transmitting said path computation request to a second path computation element  
in a third autonomous system bordering said first autonomous system; and thereafter

receiving virtual shortest path tree information from said second path computation  
5 element, said virtual shortest path tree information identifying a virtual shortest path tree  
rooted at said tail-end node and extending to one more border routers connected in both  
said first autonomous system and said third autonomous system.

9. The method of claim 8 further comprising:

10 using said virtual shortest path tree information to compute a path of said MPLS  
Traffic Engineering LSP from said head-end node to said tail-end node.

10. The method of claim 9 further comprising:

sending information identifying said path to said head-end node.

15

11. The method of claim 10 wherein said information identifying said path  
identifies border routers of said path without identifying intermediate nodes between said  
border routers.

12. The method of claim 10 wherein said information identifying said path identifies border routers of said path and intermediate nodes between said border routers.

5

13. A method for operating a first path computation element in a first area to participate in establishing an MPLS Traffic Engineering LSP from a head-end node in said first area to a tail-end node in a second area, said method comprising:

computing a virtual shortest path tree rooted at said head-end node and extending  
10 to one or more border routers connected to said first area and to a third area between said first area and said third area; and

sending information identifying said virtual shortest path tree to a second path computation element operating on a border router connected in both said third area and said second area.

15

14. The method of claim 13 further comprising:

receiving information identifying a path of said MPLS Traffic Engineering LSP from said second path computation element; and

notifying said head-end node of said path.

15. The method of claim 13 wherein said first path computation element operates on a border router connected in both said first area and said third area.

5

16. A method for operating a first path computation element connected in a first area and a second area to participate in establishing an MPLS Traffic Engineering LSP from a head-end node in a third area to a tail-end node in said first area, said method comprising:

10 receiving information identifying a virtual shortest path tree rooted at said head-end node and extending to one or more border routers connected in both said third area and said second area;

performing computations to extend said virtual shortest path tree through said second area and said third area; and

15 identifying a path for said MPLS Traffic Engineering LSP based on said extended virtual shortest path tree.

17. The method of claim 16 wherein receiving comprises:

receiving said information from a second path computation element connected in both said second area and said third area.

5

18. The method of claim 16 further comprising:

sending information identifying said path to said head-end node.

19. A method for establishing a MPLS Traffic Engineering LSP between a

10 head-end node and a tail-end node across multiple areas, said method comprising:

providing a plurality of path computation elements, each associated with a corresponding area;

using said plurality of path computation elements to recursively compute a virtual shortest path tree between a first area including said head-end node and a second area

15 including said tail-end node; and

computing a path of said MPLS Traffic Engineering LSP using said shortest path tree.

20. The method of claim 19 wherein a root of said virtual shortest path tree comprises said tail-end node and other nodes of said shortest path tree are border routers connecting ones of said multiple areas.

5

21. The method of claim 19 wherein computing a path comprises employing CSPF.

22. A method for operating a first path computation element in a first area to  
10 participate in establishing an inter-area Traffic Engineering LSP between a head-end node and a tail-end node, said method comprising:

receiving virtual shortest path tree information from a second path computation  
element in a second area, said virtual shortest path tree information identifying a shortest  
path tree rooted at said tail-end and extending to one or more border routers linking said  
15 first area and said second area;

performing computations based on said received virtual shortest path tree  
information to determine a revised virtual shortest path tree, said revised virtual shortest  
path tree extending from said tail-end node to one or more border routers linking said  
first area and a third area; and



sending information identifying said revised virtual shortest path tree to a third path computation element in said third area.

5            23.     The method of claim 22 wherein said information identifying said revised virtual shortest path tree identifies paths through border routers of said revised virtual shortest path tree without identifying intermediate nodes between said border routers of said revised virtual shortest path tree.

10           24.     The method of claim 23 wherein said information identifying said revised virtual shortest path tree identifies paths through border routers of said revised virtual shortest path tree and identifies intermediate nodes between said border routers of said revised virtual shortest path tree.

15           25.     The method of claim 24 further comprising:

prior to receiving said virtual shortest path tree information from said second path computation element, receiving a path computation request from said third path computation element and forwarding said request to said second path computation element.

26. A method for operating a first path computation element in a first area to participate in establishing an MPLS Traffic Engineering LSP from a head-end node in  
5 said first area to a tail-end node in a second area, said method comprising:

receiving a path computation request from said head-end node;

transmitting said path computation request to a second path computation element in a third area bordering said first area; and thereafter

receiving virtual shortest path tree information from said second path computation  
10 element, said virtual shortest path tree information identifying a virtual shortest path tree rooted at said tail-end node and extending to one more border routers connected in both said first area and said third area.

27. The method of claim 26 further comprising:

15 using said virtual shortest path tree information to compute a path of said MPLS Traffic Engineering LSP from said head-end node to said tail-end node.

28. The method of claim 27 further comprising:

sending information identifying said path to said head-end node.

5           29. The method of claim 28 wherein said information identifying said path identifies border routers of said path without identifying intermediate nodes between said border routers.

          30. The method of claim 28 wherein said information identifying said path  
10 identifies border routers of said path and intermediate nodes between said border routers.

          31. A computer program product for establishing a MPLS Traffic Engineering LSP between a head-end node and a tail-end node across multiple autonomous systems, said product comprising:

15           code that causes provision of a plurality of path computation elements, each associated with a corresponding autonomous system;

          code that causes use of said plurality of path computation elements to recursively compute a virtual shortest path tree between a first autonomous system including said head-end node and a second autonomous system including said tail-end node;

code that causes computation of a path of said MPLS Traffic Engineering LSP  
using said shortest path tree; and

a computer-readable storage medium that stores the codes.

5

32. The product of claim 31 wherein a root of said virtual shortest path tree  
comprises said tail-end node and other nodes of said shortest path tree are border routers  
connecting ones of said multiple autonomous systems.

10 33. The product of claim 31 wherein said code that causes computation of a  
path comprises code that causes employment of CSPF.

34. A computer program product for operating a first path computation  
element in a first autonomous system to participate in establishing an inter-autonomous  
15 system Traffic Engineering LSP between a head-end node and a tail-end node, said  
product comprising:

code that causes receipt of virtual shortest path tree information from a second  
path computation element in a second autonomous system, said virtual shortest path tree  
information identifying a shortest path tree rooted at said tail-end and extending to one or

more border routers linking said first autonomous system and said second autonomous system;

code that causes performance of computations based on said received virtual  
5 shortest path tree information to determine a revised virtual shortest path tree, said  
revised virtual shortest path tree extending from said tail-end node to one or more border  
routers linking said first autonomous system and a third autonomous system;

code that causes sending of information identifying said revised virtual shortest  
path tree to a third path computation element in said third autonomous system; and

10 a computer-readable storage medium that stores the codes.

35. The product of claim 34 wherein said information identifying said revised  
virtual shortest path tree identifies paths through border routers of said revised virtual  
shortest path tree without identifying intermediate nodes between said border routers of  
15 said revised virtual shortest path tree.

36. The product of claim 35 wherein said information identifying said revised  
virtual shortest path tree identifies paths through border routers of said revised virtual  
shortest path tree and identifies intermediate nodes between said border routers of said  
20 revised virtual shortest path tree.

37. The product of claim 34 further comprising:

code that, prior to receipt of said virtual shortest path tree information from said  
5 second path computation element, causes receipt of a path computation request from said  
third path computation element and forwarding said request to said second path  
computation element.

38. A computer program product for operating a first path computation  
10 element in a first autonomous system to participate in establishing an MPLS Traffic  
Engineering LSP from a head-end node in said first autonomous system to a tail-end node  
in a second autonomous system, said product comprising:

code that causes receipt of a path computation request from said head-end node;

code that causes transmission of said path computation request to a second path  
15 computation element in a third autonomous system bordering said first autonomous  
system;

code that causes receipt of virtual shortest path tree information from said second path computation element, said virtual shortest path tree information identifying a virtual shortest path tree rooted at said tail-end node and extending to one more border routers  
5 connected in both said first autonomous system and said third autonomous system; and

a computer-readable storage medium that stores the codes.

39. The product of claim 38 further comprising:

code that causes use of said virtual shortest path tree information to compute a  
10 path of said MPLS Traffic Engineering LSP from said head-end node to said tail-end node.

40. The product of claim 39 further comprising:

code that causes sending of information identifying said path to said head-end  
15 node.

41. The product of claim 40 wherein said information identifying said path identifies border routers of said path without identifying intermediate nodes between said border routers.

42. The product of claim 40 wherein said information identifying said path identifies border routers of said path and intermediate nodes between said border routers.

5

43. A computer program product for operating a first path computation element in a first area to participate in establishing an MPLS Traffic Engineering LSP from a head-end node in said first area to a tail-end node in a second area, said product comprising:

10 code that causes computation of a virtual shortest path tree rooted at said head-end node and extending to one or more border routers connected to said first area and to a third area between said first area and said third area;

code that causes sending of information identifying said virtual shortest path tree to a second path computation element operating on a border router connected in both said  
15 third area and said second area; and

a computer-readable medium that stores the codes.



44. The product of claim 43 further comprising:

code that causes receipt of information identifying a path of said MPLS Traffic Engineering LSP from said second path computation element; and

5 code that causes notification of said head-end node of said path.

45. The product of claim 43 wherein said first path computation element operates on a border router connected in both said first area and said third area.

10 46. A computer program product for operating a first path computation element connected in a first area and a second area to participate in establishing an MPLS Traffic Engineering LSP from a head-end node in a third area to a tail-end node in said first area, said product comprising:

code that causes receipt of information identifying a virtual shortest path tree  
15 rooted at said head-end node and extending to one or more border routers connected in both said third area and said second area;

code that causes performance of computations to extend said virtual shortest path tree through said second area and said third area;

code that causes identification of a path for said MPLS Traffic Engineering LSP based on said extended virtual shortest path tree; and

a computer-readable storage medium that stores the codes.

5

47. The computer program product of claim 46 wherein said code that causes receipt comprises:

code that causes receipt of said information from a second path computation element connected in both said second area and said third area.

10

48. The product of claim 46 further comprising:

code that causes sending of information identifying said path to said head-end node.

15

49. A computer program product for establishing a MPLS Traffic Engineering LSP between a head-end node and a tail-end node across multiple areas, said product comprising:

code that causes provision of a plurality of path computation elements, each associated with at least one corresponding area;

code that causes use of said plurality of path computation elements to recursively  
5 compute a virtual shortest path tree between a first area including said head-end node and a second area including said tail-end node;

code that causes computation of a path of said MPLS Traffic Engineering LSP using said shortest path tree; and

a computer-readable storage medium that stores the codes.

10

50. The product of claim 49 wherein a root of said virtual shortest path tree comprises said tail-end node and other nodes of said shortest path tree are border routers connecting ones of said multiple areas.

15 51. The product of claim 49 wherein said code that causes computation of a path comprises code that causes employment of CSPF.

52. A computer program product for operating a first path computation element in a first area to participate in establishing an inter-area Traffic Engineering LSP between a head-end node and a tail-end node, said product comprising:

5 code that causes receipt of virtual shortest path tree information from a second path computation element in a second area, said virtual shortest path tree information identifying a shortest path tree rooted at said tail-end and extending to one or more border routers linking said first area and said second area;

code that causes performance of computations based on said received virtual  
10 shortest path tree information to determine a revised virtual shortest path tree, said revised virtual shortest path tree extending from said tail-end node to one or more border routers linking said first area and a third area;

code that causes sending of information identifying said revised virtual shortest path tree to a third path computation element in said third area; and

15 a computer-readable medium that stores the codes.

53. The product of claim 52 wherein said information identifying said revised virtual shortest path tree identifies paths through border routers of said revised virtual shortest path tree without identifying intermediate nodes between said border routers of  
20 said revised virtual shortest path tree.

54. The product of claim 53 wherein said information identifying said revised  
virtual shortest path tree identifies paths through border routers of said revised virtual  
5 shortest path tree and identifies intermediate nodes between said border routers of said  
revised virtual shortest path tree.

55. The product of claim 52 further comprising:

code that, prior to receipt of said virtual shortest path tree information from said  
10 second path computation element, causes receipt of a path computation request from said  
third path computation element and forwarding said request to said second path  
computation element.

56. A computer program product for operating a first path computation  
15 element in a first area to participate in establishing an MPLS Traffic Engineering LSP  
from a head-end node in said first area to a tail-end node in a second area, said product  
comprising:

code that causes receipt of a path computation request from said head-end node;

code that causes transmission of said path computation request to a second path computation element in a third area bordering said first area;

code that causes receipt of virtual shortest path tree information from said second  
5 path computation element, said virtual shortest path tree information identifying a virtual shortest path tree rooted at said tail-end node and extending to one more border routers connected in both said first area and said third area; and

a computer-readable storage medium that stores the codes.

10 57. The product of claim 56 further comprising:

code that causes use of said virtual shortest path tree information to compute a path of said MPLS Traffic Engineering LSP from said head-end node to said tail-end node.

15 58. The product of claim 56 further comprising:

code that causes sending of information identifying said path to said head-end node.

59. The product of claim 58 wherein said information identifying said path identifies border routers of said path without identifying intermediate nodes between said border routers.

5

60. The product of claim 58 wherein said information identifying said path identifies border routers of said path and intermediate nodes between said border routers.

61. Apparatus for establishing a MPLS Traffic Engineering LSP between a  
10 head-end node and a tail-end node across multiple autonomous systems, said apparatus comprising:

means for providing a plurality of path computation elements, each associated with a corresponding autonomous system;

means for using said plurality of path computation elements to recursively  
15 compute a virtual shortest path tree between a first autonomous system including said head-end node and a second autonomous system including said tail-end node; and

means for computing a path of said MPLS Traffic Engineering LSP using said shortest path tree.

62. Apparatus for establishing a MPLS Traffic Engineering LSP between a head-end node and a tail-end node across multiple areas, said apparatus comprising:

means for providing a plurality of path computation elements, each associated  
5 with at least one corresponding area;

means for using said plurality of path computation elements to recursively compute a virtual shortest path tree between a first area including said head-end node and a second area including said tail-end node; and

means for computing a path of said MPLS Traffic Engineering LSP using said  
10 shortest path tree.

63. Apparatus for establishing a MPLS Traffic Engineering LSP between a head-end node and a tail-end node across multiple autonomous systems, said apparatus comprising:

a processor; and

15 a memory device that stores instructions to be executed by said processor said instructions comprising:

code that causes provision of a plurality of path computation elements, each associated with a corresponding autonomous system;



code that causes use of said plurality of path computation elements to recursively compute a virtual shortest path tree between a first autonomous system including said head-end node and a second autonomous system including said tail-end  
5 node; and

code that causes computation of a path of said MPLS Traffic Engineering LSP using said shortest path tree.

64. Apparatus for establishing a MPLS Traffic Engineering LSP between a  
10 head-end node and a tail-end node across multiple areas, said apparatus comprising:

a processor; and

a memory device that stores instructions to be executed by said processor said instructions comprising:

code that causes provision of a plurality of path computation elements,  
15 each associated with at least one corresponding area;

code that causes use of said plurality of path computation elements to recursively compute a virtual shortest path tree between a first area including said head-end node and a second area including said tail-end node; and

code that causes computation of a path of said MPLS Traffic Engineering  
LSP using said shortest path tree.